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A Matter of Timing: System Requirements for Repair and Their Temporal Dimensions

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Abstract: Research into repair within the circular economy (CE) typically focuses on technical aspects of design, policy, and markets, and often assumes or implies simplified conditions for the user/owner and the product-system to explain the barriers to scaling repair activities. By integrating life cycle and temporal dimensions (time-sequence) into a broad System of Repairability framework, we demonstrate that the decision to *repair-or-not-repair* is not the sole responsibility of the user/owner. Other factors occurring at pre-use stages of the product's life cycle significantly influence whether, and to what extent, repair is viable or possible, i.e., warranty duration, after-sale service provision, and access to necessities. In this analysis, we explore the various factors that affect ability, difficulty, and thus, the likelihood of repair activities being performed at each stage of the product's life-cycle, applying a temporal perspective. We propose a framework for considering the System of Repairability, which delineates the temporal dimensions of repair as they relate to one's 'ability to repair', as a product progresses through different life-cycle phases (i.e., breakdown vs. repair vs. disposal), and the point(s) at which the repair is considered or attempted (i.e., year of usage). Accordingly, the System of Repairability framework clarifies the decision-points, stakeholders, and necessary conditions to facilitate a repair outcome at the individual level, and thus intervention strategies for scaling repair within CE. We conclude with a brief discussion of policy implications and a future outlook on how temporal dimensions can inform policy strategies and future research.

Introduction

Repair is defined as a process through which a specified fault in a product is addressed to restore functionality, thus enabling value-retention within a circular economy (CE) (International Resource Panel, 2018). Systematic study and understanding of repair activities, and the inherent associated economic, social, and environmental opportunities, is lacking in contemporary literature.

The repairability of products is impacted by various factors that depend on the product's life cycle stage (e.g., before breakage) (McLaren et al., 2020; Svensson-Hoglund et al., 2021). Temporal (time-related) dimensions of repair are either determined, or influenced by product design, manufacturing, warranty coverage, use-conditions, and locus of control in a "system of reparability". Given the recent rise in repair-focused policy measures, there is a need to identify and understand these temporal "dimensions" to ensure that new policy and strategy interventions appropriately consider and address these dimensions.

By introducing a system-wide product life cycle perspective, it becomes apparent that the decision to *repair-or-not-repair* is not the sole responsibility of the user/owner: other factors occurring much earlier in the product's life cycle significantly influence whether, and to what extent, repair is possible (c.f., Jaeger-Erben et al., 2021; Svensson-Hoglund et al., 2021). To address the temporal (time-based) dimensions of repair, we explore the range and nature of time-related elements of repair, including the product lifecycle stages, stakeholder locus of control.

Assessment and Synthesis

Synthesis of Temporal Dimensions of Repair Barriers and Motivations

To explore the temporal dimensions of repair, we first synthesize the literature on the barriers to, and motivations for, repair. We then analyze and extract identified time-based elements of repair across five dimensions: 1) Market & Economics; 2) Culture & Perceptions; 3) Technological & Design; 4) Infrastructure & System; and 5) Legal & Regulatory (Table 1). Temporal dimensions of the reviewed barriers and motivations were further categorized as either being related to the Life Cycle Phases (e.g., Upstream/Design and Downstream/Use) of the product, or related to Temporal Distance/Time-based Elements, i.e., the passing of time (Column 2 and 3 in Table 1).

System Dimension	**Synthesis of Temporal Dimensions of Repair Barriers & Motivations**	
	Related to Life Cycle Phase	**Related to Temporal Distance / Time-based Elements**
Market & Economics	• Product development priorities focus on short-term sales and revenue targets (Upstream). • Repair necessities (tools, skills, parts) can be time-consuming and expensive to acquire (Downstream). • Quality of repair services are often sacrificed to reduce time and cost (Downstream).	• Product age and condition often have greater influence than price in repair decision-making. • Inconvenience and costs (i.e., time, effort and money).
Culture & Perceptions	• Normalization of 'upgrading' encourages material-culture (Downstream). • High speed of design changes emphasizes newness fixation and perception of obsolescence (Upstream). • Psychological obsolescence marketing messages that reiterate time-based need to 'keep-up' (Downstream).	• "New" is emphasized as desirable. • Satisfaction derived from having the 'new' thing dissipates as time passes. • Normalized convenience sets an expectation of instant needs-fulfillment - cannot wait for a repair. • Older products are devalued. • Time and effort available to engage in repair changes across user/owner lifetime.
Technological & Design	• Design-choices (e.g., use of adhesives) prevent disassembly and repair (Downstream). • Contemporary aesthetics (e.g., style, color) - products designed for 'now' (vs. future). (Upstream). • Product lifetimes intentionally short due to planned, premature and technical obsolescence (Upstream). • Designed product service life (e.g., in years) often exceeds the warranty period, leading to premature product replacement (Downstream).	• Lack of user/owner knowledge needed to assess repair needs and options. • Availability of repair necessities at time of repair. • Familiarity with the functioning of a device increases over time or as use increases.
Infrastructure & System	• Aftermarket repair options for products restricted by design (e.g., OEM authorized/certified agents) (Upstream). • Specialized repair necessities (e.g., third party tools, spares & manuals) typically not publicly available (Downstream).	• Access to repair necessities outside of OEM-authorized sphere increases as time passes from the product release date (e.g., development of alternative forms of repair necessities; reverse-engineering of a proprietary fastener).
Legal & Regulatory	• Contract law used to prevent third party repairs (Downstream) • Copyright, patents, and trademarks designed to hinder availability of spares (Upstream) • Lack of enforcement of the right to take a	• Policy tools must balance current priorities (e.g. consumer ownership rights) against future priorities (e.g., support for IP laws incentivizing innovation). • Repair undertaken more frequently when warranty is active; expired warranties

	product under warranty to a third party repairer without voidance of that warranty. Downstream) • Initial (early-period) burden of proof for Warranty lies with sellers (e.g., for 'new' product, bias towards replacement). (Downstream) • Influence of industry lobby efforts and lack of clarity and consensus regarding an owner's "right to repair" (Downstream)	encourage product replacement • With time, intellectual property law protection expires or ceases to be enforced (e.g., trade secrets become too widely known). • Later-period burden of proof for Warranty shifts to user/owner (e.g., for older products, bias dependent on user/owner).

Table 1: Synthesis of Repair Barriers, Motivations, and Inherent Temporal Dimensions (Hernandez et al., 2020; Jaeger-Erben et al., 2021; Jaeger-Erben & Proske, 2017; Laitala et al., 2021; Lefebvre, 2019; McCollough, 2020; Rivera & Lallmahomed, 2016; Svensson-Hoglund et al., 2021; Wieser & Tröger, 2018)

The Repair Process

A simplified process/sequence of events is often assumed for repair (Figure 1, (a)), however, as clarified by Lefebvre (2019), a process map of repair does not adequately capture the considerations and pre-existing conditions that ultimately influence the decision to *repair-or-not-repair* (Figure 1, (b)).

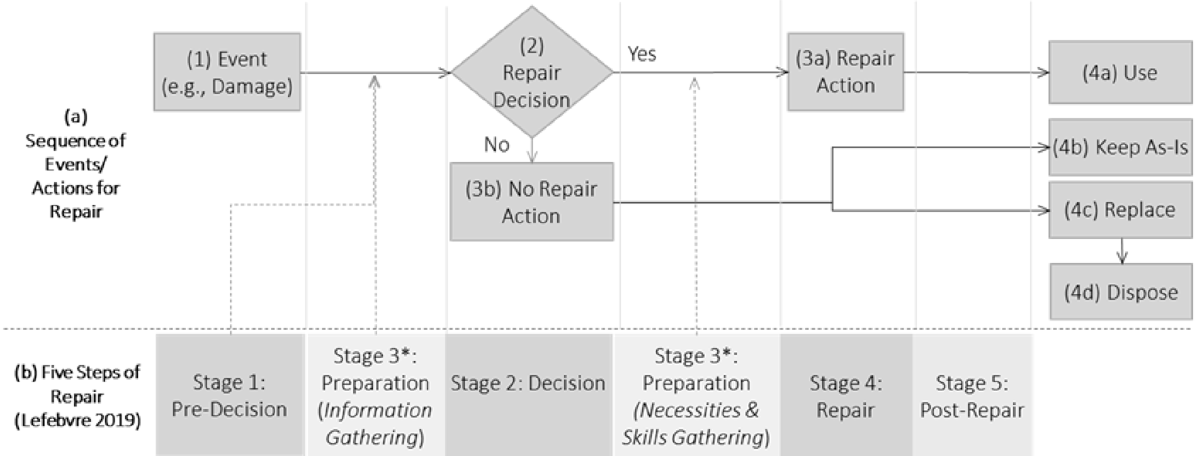

Figure 1: Simplified sequence of user-based events and decisions associated with repair, aligned with the five steps of the repair process.*Preparation activities may occur before or after a decision to repair-or-not-repair is made (Lefebvre, 2019)*

As a general process/sequence (Figure 1, (a)) illustrates that:

An event occurs (e.g., damage is inflicted) requiring repair (1). For wear-and-tear, and scheduled repairs, the timing of this event may be influenced by the extent to which proper care and use have been employed.

The user/owner decides to repair-or-not-repair the product (2). A variety of factors related to the product, the system, and the user's/owner's conditions, can influence and motivate whether repair is undertaken.

If the decision to repair is made, repair is actioned (3a), typically yielding a functioning, usable product (4a). Alternatively, if *not* repaired (3b), the user/owner may keep the product as-is (4b), replace it (4c), and/or dispose of it (4d).

The time between events varies depending on whether the product is considered to be essential by the user/owner (e.g., the sense of urgency), the presence of any emotional attachment to the product, access to repair necessities (e.g., spare parts, tools), and/or required skills (e.g. skilled professional or non-

commercial labor) (Lefebvre, 2019; Svensson-Hoglund et al., 2021).
However, according to Lefebvre (2019) (Figure 1, (b)), the steps associated with repair are more complex than a simplified decision/routing process. Prior to making the repair decision (Figure 1a, (2)), the user/owner may engage in preparation (information-gathering) activities (Figure 1b: Stage 3) to understand the nature of the damage, assess own ability to conduct the repair (e.g., DIY), identify a qualified repairer if needed, assess the acceptability of the required time for the repair work (e.g., repair can be completed according to the user's/owner's needs), assess the acceptability of the estimated repair cost (e.g., alignment with user/owner budget), and other details that may inform the user's/owner's willingness-to-pay (WTP).

Pre-Decision conditions (e.g., pre-existing user/owner attitudes, and awareness)(Figure 1b: Stage 1), and post-repair satisfaction (Figure 1b: Stage 5) can provide a reinforcing system dynamic in which past repair experiences may influence future likelihood to engage in repair again (Lefebvre, 2019).

Analysis and Discussion

The System of Repairability

Integrating these insights with other findings from the analysis of temporal dimensions of repair barriers and motivations (Table 1), three important elements of the System of Repairability are clarified (Figure 2): 1) Timing of and motivation for repair (the event); 2) The conditions and actions taken (the response); and 3) Who has the ability to influence and control the options that are available (Locus of Control). Each of these three elements has a temporal dimension to it.

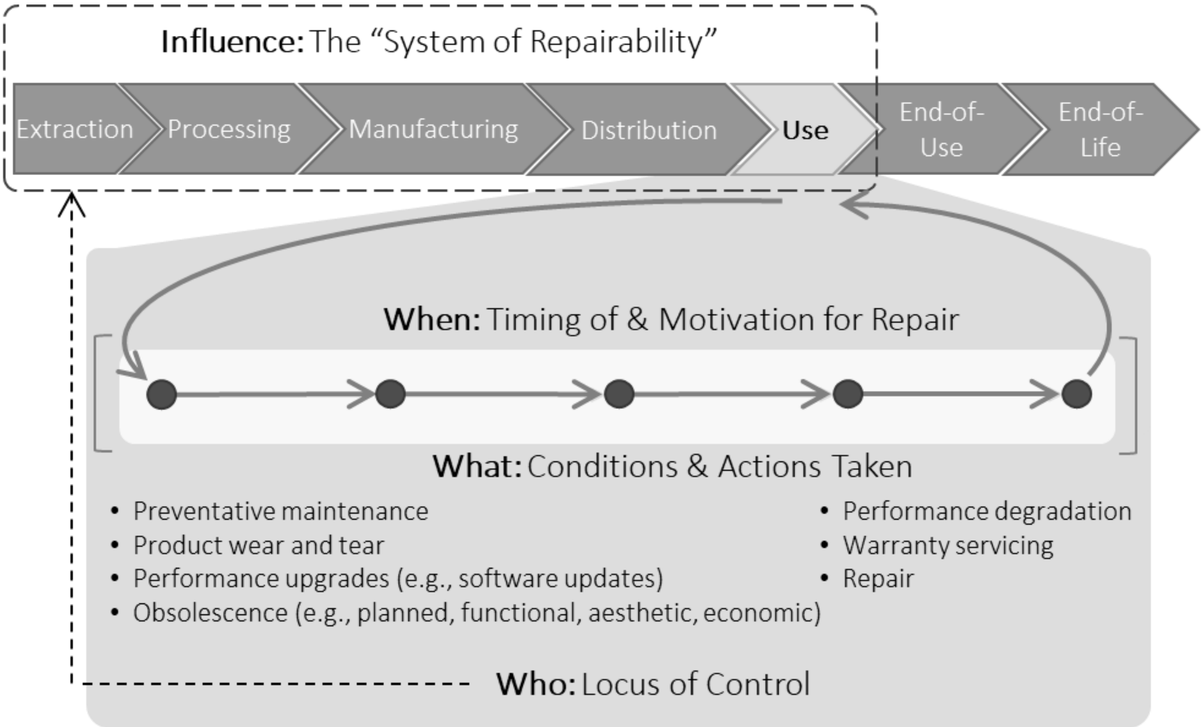

Figure 2: Overview of the system that influences whether, and the extent to which repair is possible, herein named the "System of Repairability".

Timing and Motivation for Repair (When?)

Product repair may be needed or pursued for several reasons, each with an impact on timing: Repairs necessitated by wear-and-tear typically occur relatively later in the product's service life. In contrast, a hazard event, such as a product being dropped, can occur at any time. While the nature of the damage may be predictable (e.g., a smartphone screen crack), the time at which the repair is needed is unpredictable. Finally, scheduled maintenance and repair activities may be expected or planned to occur at regular intervals, anticipated by both the owner and the producer, such as vehicle oil changes.

Figure 3 below demonstrates two distinct user/owner decision points that logically emerge from the system, and may inform strategic interventions to scale repair: First, a decision to investigate the potential for repair (Figure 3, (2a)), made after the damage event has occurred, and before any preparation is undertaken. Second, if investigated, and once the necessary information has been gathered and assessed, then a second decision to pursue (or not) repair is made (Figure 3, (2b)).

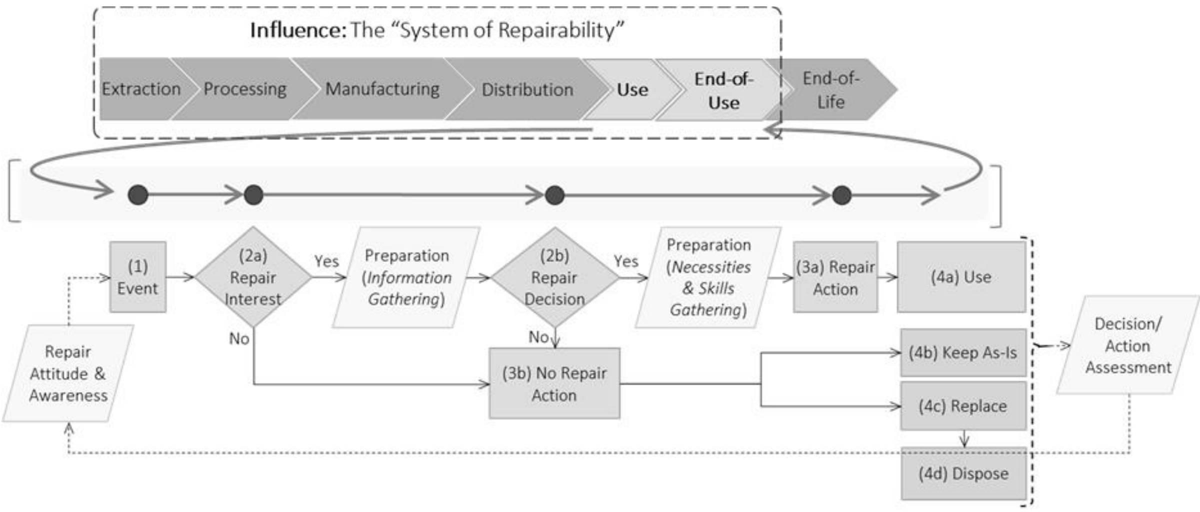

Figure 3: Expanded timing and motivation sequence within the System of Repairability, reflecting the influence that access to information, skills, and other necessities have upon the user's/owner's willingness and ability to engage in repair.

Temporal Dimensions of Conditions and Actions Taken (What?)

From Figure 3, it is clear that in the absence of information and compatibility of repair cost, knowledge, comfort, perceived value, and warranty coverage (e.g., preparation - gathering information), the decision to repair (Figure 3, (2)) may not be *viable* for the user/owner and/or it may not be *possible* to complete the repair, even if it is desired (Figure 3, (3)).

Exposure to repair during childhood and in social settings (pre-event) may increase propensity for repair prior to a repair event occurring (Lefebvre, 2019). After a repair event occurs (Figure 3, (1)), familiarity with repair and with the product may facilitate subsequent preparation stages.

Depending on when the repair need arises, the conditions of the product, user/owner, product-system, and even OEM may differ. The temporal distance between the time of product purchase and the breakage event can impact the perceived value of the product, and whether warranty coverage is still available to facilitate repair (Figure 4, (B)). Further, while the age of the product may negatively impact the likelihood of repair (Laitala et al., 2021), so too does the constant, annual release of new models touting upgraded technological functionality and compatibility (e.g., four models of iPhone released between 2017 and 2020) (Figure 4,(A)) (Apple Inc., 2021; Jaeger-Erben et al., 2021).

The temporal distance between the time of the model release date and the breakage event (Figure 4, (B)) often matters for the availability of necessities (i.e., spares, repair information and tools). Manufacturers eventually cease to manufacture spare parts for older models; however, the likelihood of someone having 'leaked' or developed repair manuals increases the longer the product has been on the market (Clapp 2018).

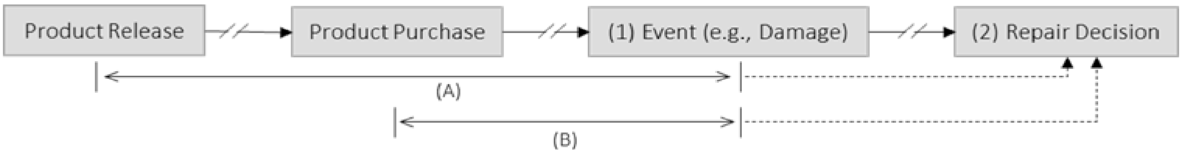

Figure 4: Influence of temporal distance upon the repair decisions, wherein (A) reflects the time that has passed between product release and breakage event, and (B) reflects the time that has passed between the product purchase and the breakage event.

Temporal Dimensions and Locus of Control (Who?)

An expanded view of the repair scenario, acknowledging the other actors within the proposed System of Repairability (product designers, OEMs, distributors, policymakers, and product owners), show that the control afforded to product owners is quite limited. From Figure 5, this expanded view of the product repair scenario demonstrates the influence, and thus the need for greater design and manufacturer accountability for decisions that negatively impact the System of Repairability.

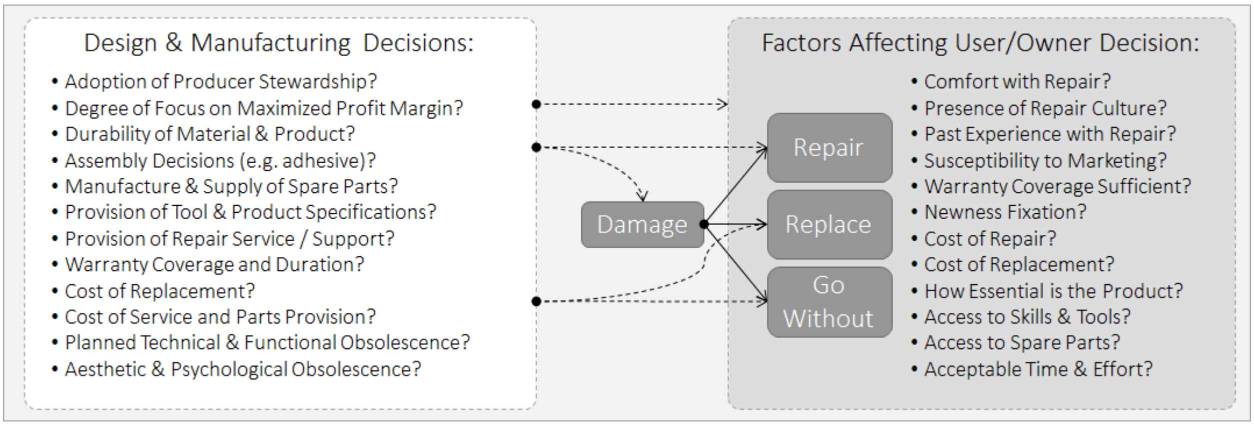

Figure 5: Overview of the expanded repair scenario, clarifying locus of control for user/owner vs. external repair system stakeholders (e.g., OEM) that influence the decision to r*epair-or-not-repair*.

Policy Implications

Policymakers looking to scale repair activities must ensure complementary and effective policy interventions that facilitate the alleviation of barriers to repair that are often hidden by oversimplified process-structures, or overshadowed by established corporate systems and priorities. From the System of Repairability framework, several key policy opportunities emerge: First, forward-looking design requirements for OEMs to ensure the technical possibility of repair, and that repairability information is clearly communicated to consumers prior to purchase, e.g., a repairability index (Stone, 2021). This can build-in the potential for repair as an inherent element of the product life cycle, and improves user/owner knowledge. Second, the assignment of responsibility via policy mechanisms for assuring viable aftermarkets and supply of spare parts for future models, whether by the OEM or third party agents. This can build capacity and opportunity for products to remain in-use through repair, addressing some of the “variable” system conditions. Finally, more immediate measures directed at the use-phase conditions, such as tax-reduction for repair services (Milios, 2021) and enforcement of consumer law to protect the interests of users/owners who wish to engage in repair. Improvements to transparency and provision of product information to consumers can address issues of information asymmetry in the market, and lead to improved repair propensity (Lefebvre, 2019) and trust between users/owners and other stakeholders in the System of Repairability, e.g., through a credible certification scheme ensuring the quality of product repairs (Gåvertsson et al., 2020).

Conclusions

Circular economy is built-upon a comprehensive understanding of product lifecycles, and the potential to retain products and their inherent value within economic systems, for longer. By considering the temporal (time-based) dimensions of repair, this work reveals that scaling repair may be as much a "matter of timing" (e.g., when a decision, need, or activity arises), as it is a technical challenge (e.g., availability of spare parts and infrastructure), and a social challenge (e.g., consumer's willingness to pay, physical access, awareness, motivation). Challenges of scaling and optimizing for repair within a CE are compounded by factors and conditions determined by value-chain actors (e.g., product designer) who are spatially and temporally distant from the user/owner. Further, there are few effective feedback mechanisms available to enable mitigation of these barriers across the product's life cycle without the intervention of policymakers.

In order to meaningfully pursue this vision in the context of a scaled repair society, use-phase complexity and conditions that currently inhibit the scaling of repair must be better understood and tackled, including the ease and convenience of a system designed for replacement instead of repair.

Across the policy opportunities mentioned above, the temporal distances and dimensions must be considered to ensure reparability under a wide range of evolving conditions for the user/owner over time. This Framework needs to be further developed in future research, as well as applied to processes of developing appropriate policy mix (Milios, 2018) of available tools (Svensson-Hoglund et al., 2021), with a life cycle perspective.

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